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REVIEW OF SOVIET PHOTOGRAMMETRIC PROCEDURES

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REVIEW OF SOVIET PHOTOGRAMMETRIC PROCEDURES

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..."The task of maximum use of natural resources, set forth by the 19th Congress of the Party, is connected with the execution of large-scale and complex investigations, the basic aim of which is the improvement of geographic distribution of industrial establishments, which has in view as far as possible bringing industry close to the sources of raw material and fuel.

This directive demands of science a multi-sided study and mastery of the vast expanses of our East and South. Before the Academy of Sciences is laid the task -- on the basis of broadly developed geological, geographic, and economic investigations, carried on together with various offices and ministries, -- to furnish the scientific foundation of the proposed development of the national economy of a number of eastern and sourthern regions of the Soviet Union.

The use of new methods of aerial investigation for territorial (air) route research of a locality has basically changed the tempo of investigative operations"...

Excerpt from a speech by Academician,

A. N. Nesmeyanov

printed in

Vestnik Akademiya Nauk SSSR
Vyp. 3 (March), 1953

[redacted]

SUMMARY AND CONCLUSIONS

The Soviets appear to have made several original contributions in the field of photogrammetry. These are probably, in the order of their importance, as follows:

1. The development of super wide-angle camera lenses.
2. The development of efficient small-scale mapping systems based on the "differentiated" method, though the method itself is not an entirely original concept of the Russians.
3. The concept and design of Drobyshev's stereometers.
4. The "straight-line" method of Romanovskiy.

Major trends in Soviet photogrammetrical methods as commented on more fully later would seem to be

1. A recognition of the importance of the optics, and a development along those lines possibly exceeding our own, if the reports on their lenses are true.
2. The tendency to make the corrections for orientation mechanically, rather than by homolog or optical means.
3. The use of numerical computations where we tend to compute by analog, or not to compute explicitly at all.

[redacted]

PART I.

A. INTRODUCTION

In any attempt to evaluate photogrammetrical mapping procedures in the U.S.S.R. the fact that photogrammetry is a young subject which has not yet reached maturity must be constantly kept in mind. Though photogrammetrical surveys on the ground were made prior to World War I, aerial photography - at first as an auxiliary aid to the mapping of detail by conventional ground methods - became a major tool of the map maker much later.

Only in the last twenty years have governments fully recognized that mapping programs, to be efficiently completed, must utilize aerial photography. Furthermore, it has only been in this period that photogrammetrical theory, techniques and procedures have been developed to the point where it has been possible to organize photogrammetrical survey operations in a rational and economical manner suitable for mapping vast areas.

It would seem dangerous to assume from the fact that techniques and procedures differ from country to country and vary in accuracy that this is due to the technical superiority of one country over another. Technical superiority may exist, but in the main the organization of photogrammetry and the development of different techniques and procedures in different countries would seem largely to depend on their mapping needs and whether these can be realized in a reasonably short time. These in turn will depend to a great extent on the sizes of the countries and the densities of their populations and, to a lesser extent, on their political structure and industrial stability.

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A good illustration of this variation in practice is the difference between Western European and American photogrammetrical practice. Since Western Europe consists of a number of comparatively small countries, each fairly adequately mapped before the advent of aerial photogrammetry, the effort there has been largely in the development of techniques, procedures and instruments of greater and greater accuracy and for the utilization of photogrammetry for mapping on larger and larger scales. In the U.S.A. the effort has been devoted more to reaching an acceptable accuracy for the mapping of large unmapped areas on comparatively smaller scales with the emphasis on speed and economy of operation.

Moreover, the money appropriations for mapping comparable areas and the number of properly trained and experienced photogrammetrists per unit of area is higher in Europe than in America because of the over-all greater density of population. This does not necessarily imply that the competency of American photogrammetrists as a whole is lower than in Europe, only that it must be spread out thinner. Furthermore this justifies, and to a certain extent enforces, the development of techniques and procedures which can utilize comparatively unskilled labor in many of the photogrammetrical operations.

Until quite recently, because of the lack of a true appreciation of these underlying causes, European photogrammetrists have considered their technical competence as being superior to that of their counterparts in the U.S.A. . But though the average European photogrammetrist may be better trained than the average American photogrammetrist in the theoretical aspects of the subject, the more broad-minded Europeans are now ready to admit, from the practical standpoint of competency, that American photogrammetry is on a par with that in Europe considering the different mapping requirements in each region.

Overall mapping requirements and conditions in the U.S.S.R. are much more comparable to those in the U.S.A. than to those in Western Europe. However, the area of the U.S.S.R. - over eight and one-half million square miles - is approximately twice that of the U.S.A. and the population, on the other hand estimated at the present time to be less than 200 million, is not very much larger than the population of the U.S.A. Thus, if there is any validity in the foregoing argument one might expect to find (a) fewer competent photogrammetrists per unit area in the U.S.S.R. than in the U.S.A., (b) that standard mapping scales are on the whole smaller, (c) that accuracy specifications are less strict, and (d) that the techniques and procedures and instruments that have been developed are cruder and more easily handled by those not fully acquainted with photogrammetrical theory.

In many respect these conditions appear to have been true up until recently, though again as in the case of the comparison between Western Europe and the U.S.A. this does not in itself reflect on the over-all competency of the photogrammetric profession in the U.S.S.R. Indeed one gets the impression that photogrammetrical operations in Russia are extremely well organized and that the facilities for training in the theory and practice of photogrammetry are considerably better than in the U.S.A. Furthermore there seems to be no doubt that that with the aid of photogrammetry the U.S.S.R. in recent years has had an enormously greater output of topographical mapping than the U.S.A.

The reason for this state of affairs would seem to be fairly obvious. The great period of industrial expansion in the U.S.A. took place before the advent of photogrammetry, whereas in the U.S.S.R. it is at its height. Consequently in the U.S.S.R. there is an urgent and pressing need for maps not only for military but for economic purposes. These needs cannot but be heeded by the Soviet government. In the U.S.A., though the need for the completion of a national map is fully recognized, its urgency is not so apparent. Thus, the budgetary allowance for civilian mapping in proportion to other budgetary needs is probably far greater in the U.S.S.R. than in the U.S.A.

In spite of this it can be reasonably inferred from the material reviewed that the supply of precision instruments and trained personnel has not been sufficient for the demand in the U.S.S.R. up to the present. Graphical methods seem to be still widely employed and the instructions for mapping are apparently directed toward personnel not fully trained or highly experienced. Some of the mapping apparently is still done by plane table on the ground (Siberia). Much of the actual photogrammetry is accomplished with the use of graphics approximating instruments. Also, photographic materials and their processing do not seem to be as good in the U.S.S.R. as in either Europe or the U.S.A.

The outstanding exception to this situation would appear to be in the advances the Soviets have made in the design and production of wide-angle aerial camera lenses. These would appear to be of very high quality in regard to the evenness of resolution and in the smallness of their distortion. One has, of course, to treat the claims about these lenses with considerable scepticism until samples are available for testing in this country.

B. HISTORICAL DEVELOPMENT OF PHOTOGRAMMETRY IN THE U.S.S.R.

It is difficult to determine how far Soviet photogrammetry has developed independently from that of Western Europe and that of the U.S.A. This is because of the propaganda line that always appears in any historical accounts of developments in the U.S.S.R..

This propaganda has noticeably increased since the end of World War II. For instance, Veselovskiy in his book published in 1945(1), is quite frank in stating that stereo-photogrammetric instruments of foreign make have been used almost exclusively up to the time of writing. Skiridov, however, in his book published in 1951(2), though apparently well versed in foreign methods and instruments, goes to great pains to claim priority in development for almost everything connected with photogrammetry. In his "short historical review of aerial scale photogrammetry in the U.S.S.R." (page 6-11 of his book) there are some illuminating comments.

It is stated that in 1925 that the stereo-planograph was introduced in the U.S.S.R. though at this point he does not mention the Zeiss Company who were its originators. According to the writer its potentialities were immediately recognized in the U.S.S.R., far more so in fact than in the country of its origin.

1926 is given as the date when the first Soviet treatise on the analysis of the exterior orientation of a single aerial photograph was published. This was written by N. G. Kell'(3) and Skiridov considers it to be the original treatise on the subject. Nevertheless, this particular and fundamental problem had been comprehensively analyzed long before, notably by Finsterwalder in Germany in 1897, by Roussilhe in France in 1917 and by McCaw in Great Britain in 1922.

In 1928 Skiridov himself published an analytical solution of the problem, equally fundamental, of the relative orientation between photographs and the means thus provided for spatial photo-triangulation. However he was preceded in this, for according to O. VonGruber, the theoretical foundation was laid by Finsterwalder as early as 1899 and practice applications of the theory were suggested by other German and French scientists before the first world war. Certainly a thoroughly practical method was in existence before 1928, for instance in the work of H. G. Fourcade published in the Transactions of the Royal Society of South Africa in 1926.

1930 is the date given when Gapochko[4] started working out a method of drawing relief on the aerial photographs themselves with the help of stereoscopes and then reducing it to map form. An analogous method had been completely worked out and put into practice in the U.S.A. in the early twenties. This was the famous Brock method.

The leading photogrammetrical instrument designer in Russia seems undoubtedly to have been and to be F. E. Drobyshev. He had, according to Veselovskiy, designed a nine-lens camera in 1931. It would appear that the most original photogrammetric instrument that the Russians have been able to develop has been his stereometer. He started to work on this in 1931 and the first instrument was completed in 1934[5, 6, 7]. However, it is worth noting that the instrument did not come into general use until after World War II. From a mechanical point of view as noted later in this report the principle features of the stereometer, of which there have been several versions, is that both photographs in the instruments are maintained in co-planer relationship at all times regardless of the tilts which may have existed at the time of exposure; that the line of sight of the optical viewing system is kept perpendicular to the plane of the photographs at all times and that by means of ingenious mechanical devices parallaxes are obtained from coordinate movements of the photographs in their common plane. No comparable instruments are produced in this country or in Western Europe though in the last analysis the instruments do not perform any task that some European and American instruments do not also perform.

The claims that the Soviets were the first to produce satisfactory wide-angle aerial camera lenses may be true. This development was due to the work of M. M. Rusinov who produced in 1931[8] the "Liar objective" with an angular field of view of 100°. In this connection it should be noted that Skiridov states with pride that the later super-wide-angle objective "Russar" with a field of view of 122° has no counterparts outside Russia.

In 1936 under the leadership of M. D. Konshin and G. V. Romanovskiy there were developed methods and procedures for mapping from aerial photographs on the scales of 1:50,000 and 1:100,000. Romanovskiy also introduced at this time the "straight line" method for determining elevations through a series of near-vertical photographs (see appendix). This is undoubtedly an original technique. The principle feature in these mapping systems is called the "differentiated method". It divides the mapping process into two separate parts; first, the mapping of the planimetry and second, the plotting of the relief. Great economy is claimed for this procedure since it involves simplified instrumentation and lower standards of training for those engaged in the work of applying it. Furthermore, the procedure can be stopped without wasted effort in those cases where relief features are not required. Later in this report the following comment is made about this method "...(it) is similar to the Brock method. It is the same in basic concept but has been extended and improved in some important respects and in a few respects is not as good... It is ironical that the only American mapping method (originating in America) - the Brock - should have been neglected here but taken over by the Russians and that one of the better European inventions - the Multiplex - should have been neglected there but taken over by us." Russia also claims to have developed further the Multiplex for purposes of aerial triangulation, using extremely wide-angle field cameras.

In 1938 a method of spatial photo-triangulation based on computing formulas by Zhukov was adopted. This approach was one of the earliest to be considered in Western Europe but was later abandoned with the introduction of the universal type of stereo-plotting instrument. It would seem important then to note that this approach using stereo-comparators and analytical computations has been given much consideration by the Soviets in recent years while in Europe the emphasis still is to a great extent on the purely instrumental or analog solutions. This is especially interesting because there has been, still more recently, both in Europe and the U.S.A. a re-examination and further development of the analytical approach, induced by the introduction of electronic computing devices.

In commenting about the most recent developments in photogrammetry in the U.S.S.R., Skiridov mentions the use of a multi-camera multiplex in mapping mountainous regions* and also lays emphasis on the efforts being

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* First introduced for aerial surveying by Finland.

made to determine the position of air stations and camera orientations at the time of exposure by means of statescopes and mechanical pilots. Finally it is briefly mentioned that position location by means of radar has begun to be used. However, there is no elaboration of this statement in the material under review.

PART II.

SOVIET METHODS AND PROCEDURES

A. MAPPING SCALES AND PROCEDURES

According to Veselovskiy(1), in 1945 original surveys and map compilations were being made from air photographs on six different scales, namely: 1:10,000, 1:25,000, 1:50,000, 1:100,000, 1:200,000, 1:500,000. The scale of 1:100,000 was the basic maping scale with 20-meter contour intervals in flat country and 40-meters in mountainous regions. The larger scales were used in highly developed areas and for special purpose maps. The smaller scales were used for reconnaissance maps in undeveloped and unexplored areas.

However, by 1951 according to Skiridov(2), the decision had been made to map the country on a basic scale of 1:25,000 with selected areas to be filled in with scales varying from 1:2,000 to 1:10,000. This might be taken to mean that the enormous task of completing the 1:100,000 scale map of the country had already been effected. From other sources it does appear that a great deal of mapping on the scale of 1:100,000 has already been accomplished. It, however, seems inconceivable that mapping on this scale is anything like completed, if one considers the area involved and the fact that the mapping of the U.S.A. on a comparable scale (1 mile to the inch) is not by any means finished. One is, therefore, inclined to believe that except in highly developed areas, photogrammetrical procedures will continue to be directed towards mapping on the scale of 1:100,000 for many years to come. Evidence to this effect is contained in the extremely comprehensive and detailed instructions contained in Part II of the Instructions for Topographic Surveys on the Scale of 1:100,000 (9).* This manual which deals with photogrammetric compilations was first published in 1942 and has been revised in 1950 to include many new procedures.

In 1945 Veselovskiy also stated that the methods of compiling maps on a scale of 1:100,000 were not regarded as firmly established. This is certainly borne out in the second edition of the "Instructions" which is replete with alternative procedures for undertaking identical operations. Moreover, these reveal a tremendous effort to take care of all contingencies and to make it possible to use personnel not fully trained in photogrammetrical theory by relieving them of troublesome decisions when unexpected technical difficulties arise. In several cases, for instance, the Instructions insist that when a certain procedure does not realize the required accuracy that the work must then be handed over for its solution to the "Chief of the Brigade" or, in special cases, to the "Chief of the Department".

A certain amount of freedom appears to be given to the local survey supervisor on the methods to be employed in mapping any particular small region. Guiding considerations in general are that in areas with differences of elevations of less than 300 meters per photograph the maps should

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be compiled from photo-maps or controlled mosaics on which have been drawn contour lines obtained stereoscopically. In mountainous areas on the other hand the contours are to be drawn directly on the map from aerial photographs by means of a stereoscopic plotting instrument, the photographs having already been adequately controlled.

Within this general framework the detailed alternative procedures are numerous and it would seem that the guiding rule is to choose the more approximate method, provided the necessary accuracy is obtainable, because it is generally the simplest and requires less instrumentation. Furthermore, it is evident that the local survey organizations do not have a free selection of instrumental equipment and must often make shift with what is supplied them. This is still another indication of the lack of standardization and of the shortage of the most up-to-date equipment.

In order to obtain a definite picture of the great variety of procedures given in the "Instructions" the general subjects discussed therein are summarized below. Detailed comments may be found in Appendix I.

The point is made in the introduction to the Instructions that the newer alternative procedures can be introduced without disrupting the technological program as a whole. Actually, the new procedures which were introduced in the second edition include the methods which utilize statoscope recordings in spatial photo-triangulation, the use of a multiplex for extending control, the use of the (RP-6) stereoscopic drawing apparatus and the transference by means of a single multiplex projector of detail from the photograph to the map. Thus it will be seen that the innovations are considerable and that there appears to be a trend towards using methods which are more comparable to those in use in Europe and the

U.S.A., though the better features of the "differentiated method" are maintained.

However, it would seem likely that those in command of photogrammetrical operations and confronted with the policy decision of changing the basic mapping scale from 1:100,000 to 1:25,000 must be faced with formidable problems of reorganization. Many of the more approximate and simple methods will have to be replaced by those which are more theoretically correct and therefore more precise. They must have on their hands, if the accounts of the vast amount of mapping that has already been achieved are correct, a great number of people well trained and experienced in the simpler methods. These must be retrained. Such a reorganization of method and retraining of personnel cannot be done overnight with efficiency and without disrupting the general mapping program. It appears that the Soviets are attacking these problems sensibly and introducing the new techniques by degrees and as alternatives to the older procedures.

APPENDIX I

Comments and Discussion [redacted] 25X1A5a1

on the Soviet book entitled,

Nastavleniye po topograficheskoy s"yemke v masshtabe 1:100,000, Chast' II. Fotogrammetricheskiye raboty.

(Instructions for Topographic Surveys on a 1:100,000 Scale, Part II, Photogrammetric Operations)

Second Edition, GUGK, 1950.

Note: Paragraphs and itemized numerations are identical with those in the original text.

I. Introduction (No comment)

II. Compilation of Photo-Maps and Controlled Mosaics

A. Compilation of the base horizontal control sheet

1. Where differences of elevation are more than 100 meters per photograph.

2. For mountainous country in which case the nadir point or its approximation must first be determined.

Various alternatives and procedures are discussed for undertaking this part of the operation depending to a large extent on the availability of ground control points. In general, the network of control is built up by radial line intersections using principle point base lines or nadir point base lines as conditions require. However, none of the alternatives uses the slotted template technique. At this stage special points are chosen and their horizontal positions determined for the purpose of photo-rectification which is the next step.

B. Rectification of Individual Photographs

Different instructions are given for this operation depending on the type of photo-rectifier available. If the range in elevation per photograph exceeds 100 meters a separate rectification is made for each elevation zone or, when convenient, rectification is made to a slanted plane which represents an average reference plane for the area. The method of rectification in each case must be by the trial and error method using the points which have been previously selected for rectification purposes.

C. Mounting the Photo-map with the Aid of the Horizontal Control Sheet

D. Preparation of Controlled Mosaics

The distinction between a photo-map and a controlled mosaic is not clear here because apparently in both case, the photographs must be rectified.

III. Stereo-Photogrammetric Methods for the Determination of Elevations and the Representation of Relief.

Six alternative procedures are given in detail in this section.

A. The Method of the Central Scientific Research Institute of Geodesy, Aerial-Surveying and Cartography

This consists of the following nine, separate steps:

1. Preliminary planning, identification and selection of points to be used, etc.
2. Determination of the elements of relative orientation.
3. Determination of x parallaxes and air-base lengths.
4. Extension of the horizontal control network.
5. Determination of the corrections to be introduced into the initial values of relative orientation.

6. Determination of the elevations of the air-stations.

7. Determination of differences in the elevations of selected points in the area.

8. Absolute orientation of the flight lines and the photogrammetric determinations of the absolute altitudes of points in the terrain.

9. Adjustment of the whole network including the elements of orientation.

Relative orientation is done either on a stereometer or on a stereocomparator; in the latter case more computation is involved. A simplified method of extending control is allowable if the number of air-bases between control points does not exceed six and provided the tilts of the photographs of the photographs are well within a limit of three degrees.

In the extension of horizontal control the nadir points are computed whereas the pass points are obtained graphically.

B. This method is essentially the same as A except that reliance is placed on a preliminary analysis of statoscope recordings taken during the flight and which enable the relative heights of the air-stations to be determined.

C. In this alternative the wide-angle multiplex is used throughout. When the stage is reached for absolute orientation if the closing errors in elevation are small they are adjusted graphically. However, if the elevation errors exceed 5 mm. on the scale of plot, computation is introduced.

D. This is the same as C except that statoscope recordings are utilized. Apparently the multiplex wide-angle method is usually employed for what are called "main flight lines". These appear to be these which have at least three ground determined elevation control points and one horizontal point at each end.

E. This method introduces the "straight-line method" for determining elevations which apparently does not require preliminary relative orientation of the photographs and enables vertical control to be extended along strips and across overlapping strips. It is not used when the relief exceeds 100 meters per photograph.

F. This method uses the stereometer for extending the vertical control. As in E it is only used when relief does not exceed 100 meters per photograph. In using the stereometer for this purpose, two different procedures are described in detail.

IV. Sketching Contour Lines with the Aid of Simple Stereoscopes Having Wide Fields of View

It is remarkable that fully automatic plotting instruments are not used and that the contour lines are sketched as a rule on the photographs. When additional vertical control is needed it is obtained by means of simple parallactic rules. Of course, as is noted in the Instructions, controlled mosaics and photo-maps which have been rectified by zones cannot be used in this procedure. Emphasis is based on the correct interpretation of the landscape by means of these interpolated contour lines especially from the geomorphological point of view and the photographs apparently are invariably also interpreted on the ground by field survey parties who utilize extra prints for this purpose.

A. Instructions are introduced here for the use of Drobyshev's topographic stereometer. With this instrument the orientation of a pair of photographs can be effected, provided there are at least four elevation control points in the stereoscopic model.

V. Compilation of the Base Maps

Several methods are described. One is a visual transference of the material from the contact print to the photo-map. Another is to transfer the map data by means of a special stereoscope having variable magnification so that photographic images and the photo plans may be seen stereoscopically at the same time. The contour lines are then drawn in by hand on the photo plan. In mountainous country a single multiplex projector is used for transferring contour lines and other details which have been drawn on the photographs to the base map. This involves raising or lowering the projector as the work proceeds in order to adjust for scale variation. Finally if the multiplex projector is not available and a photo-rectifier projector has to be used scale adjustments are computed by special formulas.

VI. Compilation of a topographic map with the help of a stereoscopic drawing instrument.

This is the one and only case in the Instructions where the contour lines and planimetric details are drawn directly from the photographs onto the map. The instrument, (RP-6), is quite simple and is virtually a stereoscopic camera lucida. The observer sees the plastic image of the landscape and at the same time the point of the plotting pencil.

APPENDIX II.

Review of Fotogrammetriya (Photogrammetry), by N. N. Veselovskiy(1)*

Published in Moscow in 1945 by the Geodetic and Cartographic Literature Publishing House at the Council of Peoples Commissars of the U.S.S.R.

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Note: The reviewer has no familiarity with the Russian language. He has, however, in addition to a photostat copy of the original text been provided with an unedited translation of the very detailed table of contents and selected text passages of seeming importance.

1) Scope of Book

The aim of the book is to give a rather full account of photogrammetric theory and contemporary Russian practice. In the author's introductory note however, he states that certain problems have not been dealt with fully or at all. These include methods for determining exterior orientation during flight, and film distortion and its influence on the precision of photogrammetrical processes.

The book was published at the end of the war with Germany and was based on a series of lectures which were probably given in wartime. As such, it is a praise-worthy effort, as good if not better in its organization and completeness as the first edition of the Manual of Photogrammetry, published by the American Society of Photogrammetry at about the same time (1944). The book is perhaps more comparable to the Professional Papers of the British Air Survey Committee which were published over a period of about twelve years starting in 1925. In this reviewer's opinion, the presentation of the geometry and mathematics of photogrammetry is better balanced and more complete than that in any of the contemporary

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textbooks on photogrammetry written in English for student consumption and this includes those by Hotine and Hart in Great Britain and Talley and Bagley in the U.S.A. Much more attention is paid to the problems of error accumulation. Nevertheless, the methods for adjusting aerial triangulation would seem to be not fully developed theoretically and comparable to those suggested by Hotine in Professional Paper of the Air Survey Committee, No. 7. (British)

There is, of course, evidence of national bias in the book. Much of the photogrammetric development, described as being original in the U.S.S.R., appears to have been copied in whole or in part from the work accomplished in other countries.

The book might have been more carefully integrated. Ground photogrammetry is discussed at the end and one gets the impression that this section was added almost as an afterthought. The spatial extension of control is treated quite independently and much later in the book than the methods of extending control horizontally by radial line methods - there being interposed the whole subject of photo-rectification and the making of photo-maps. However, this seeming divorce of the two principal techniques for extending control is perhaps understandable when the general system of producing maps on various scales in Russia is appreciated. This is described towards the end of the book (Chapter 31).

2) Methods of Mapping on Various Scales in the U.S.S.R.

Original surveys and map compilations were being made in 1945 on the following scales: 1:10,000, 1:25,000, 1:50,000, 1:100,000, 1:200,000 and 1:500,000. For scales of 1:50,000 and larger, hypsometry was obtained almost entirely by ground field parties. In areas of no great relief these parties were supplied with photo-mosaics and the process of determining elevations carried along at the same time as field checking and geographical interpretation. Apart from supplying detail the aerial photograph was used for supplementing ground control by means of horizontal radial line traverse. In mountainous country the maps were usually constructed from the individual photographs without the intervening mosaic. It is, however, noted that at the time of writing successful experiments had been undertaken in drawing relief features by means of the stereometers of Drobyshev.

On the scale of 1:100,000, photographs from multi-lens cameras were previously used, but because of the complicated procedure they were discarded in favor of single-lens photography taken with wide-angle objectives having focal lengths of 100 mm.

It is stated that methods of compiling maps on a scale of 1:100,000 cannot be regarded as firmly established and a variety of methods are described, some suitable for flat country and some for mountainous country. In all methods great reliance is placed on ground field work consisting mainly of tachyometrical traverses for tying in local radial line aerial triangulations. In flat country these traverses are run perpendicularly to the flight lines and spaced about four stereoscopic pairs apart. In mountainous country, spatial photo-triangulation is often used for elevation control, but this procedure apparently does not altogether eliminate the usual horizontal radial line traverses and their control by ground traverse or plane table survey. Discontinuous form lines are often sketched on the photographs with the aid of simple stereoscopes and adjusted later to the proper contour interval in the field.

Methods for the compilation of maps on 1:200,000 scale from aerial photographs are less developed than for the larger scales. It is concluded that the basic method for compiling planimetry should consist in assembling uncontrolled mosaics from single-lens photography, the scale being obtained, apparently, largely from navigational data. (This statement is the reviewer's own interpretation of what in the translation appears to be a rather involved procedure.) Methods for obtaining relief appear to be similar to those employed for the 1:100,000 scale. The need for geographic interpretation and generalization is stressed.

No methods of utilizing aerial photographs for the 1:500,000 scale maps had been worked out in 1945, and the author states this as extremely unfortunate because this scale is a basic one for sparsely populated regions in the U.S.S.R. However, a scheme depending on the construction of a special four lens camera is given, which would appear to be basically sounder than the trimetrogon system. All four objectives have their optical axes parallel; one is for vertical photography, two, lateral obliques and one for forward and rearward pointing obliques. The field of view is deflected onto a common film base by means of prisms in the case of the oblique photograph. In order to bring the scales of the obliques more nearly to that of the vertical photograph the focal length for the vertical picture is 100 mm, while that for the obliques is 160 mm. The photography in the direction of the line of flight is used to increase the precision in relative orientation and longitudinal tilt (x tilt).

Aircraft is used at speeds up to 400 km an hour for time-saving purposes and flight lines are up to 100 km in length. As a general practice, spatial triangulation is used for obtaining elevations, bridging being contemplated up to 22 km when elevation tolerances of 20 meters are acceptable, and up to 90 km if the tolerances are 40 meters. A parallactic grid stereoscope is used for relief interpretation. The approximate and so-called "straight-line method" of control extension is used in flat regions and a specially designed rectifying printer is supplied to aid in the transfer of planimetric detail to the map.

It is of importance and great interest to discover whether this type of reconnaissance mapping has by now been put into routine practice or has been abandoned because of unforeseen difficulties.

To this reviewer the matter of most interest in this summary of Russian mapping activities is that the Russian cartographers in 1945, while realizing the need for utilizing aerial photography to a greater extent than previously, have nevertheless developed methods for larger scales which are dependent on a combination of photogrammetry, ground field checking and detailed ground surveying. This is perhaps understandable because a map is lifeless if it does not reflect a close-up knowledge of the terrain and the human activity thereon. In America this can largely be gleaned second-hand from a more or less literate population, whereas in the U.S.S.R. such geographical intimacy must be obtained first-hand. So it may be sensible to organize the mapping activities in the ways described. Furthermore, if this interpretation of the situation is correct then it partially explains why the only really new photogrammetrical instrument developed up to 1945 in the U.S.S.R. is Drobyshev's stereometer. This measures rectified x and y parallaxes and can be used in a comparatively simple manner for orienting pairs of photographs provided the elevations of at least five points imaged in the overlap are known.

In connection with the general viewpoint the following broad statements are made (referring to the orignal text).

p. 14, "Development of stereo-photogrammetric operations in the U.S.S.R. has been slow due to lack of instruments chiefly those necessary to processing the photographs. While instruments of foreign make have previously been used, recently as a result of much work, experimental stages have been passed through and instruments for mapping on scales of 1:50,000 and 1:100,000 are being produced in the U.S.S.R. Methods combining ground survey and aerial photography have been more developed than any other and have been widely used for mapping on scales of 1:10,000 and 1:25,000."

p. 91, "Determination of exterior orientation by photogrammetry is one of the basic problems at the present moment."

p. 173, (After an analysis). "Thus we see that the precisions of analytical and graphical radial line triangulation are close to one another but the former requires much more photogrammetric processing and computation."

p. 278, "Determination of elements of exterior orientation in flight is of greatest importance in the development of contemporary photogrammetry. Research work in connection with the application of gyroscopic instruments is in progress. If the vertical position of the optical axis can be established with a precision of from ten to twenty minutes, rectification of aerial photographs will become unnecessary and will be replaced by bringing them to a predetermined scale."

p. 296, "Spatial photo-triangulation becomes simpler when it is used in conjunction with plane radial triangulation and when the elevations are determined by ordinary (?) methods."

p. 309, "Instruments of the universal type such as the Stereoplanigraph of Zeiss are not popular in the U.S.S.R., and their number is greatly limited because of their low productivity in extensive cartographic work. The use of this type of instrument is restricted to the compilation of large scale special purpose maps and for spatial photo-triangulation. By splitting the photogrammetric process up into steps a larger productiveness is obtained than by the use of the universal methods, and the process becomes more economical. It is therefore widely used in the U.S.S.R. for planimetric mapping on intermediate and small scales."

p. 388, "Methods for the revision of old maps by aerial photography are not sufficiently developed. There can be no doubt however, that this problem is about to become very real and equal in importance to that of mapping unsurveyed areas."

3) <u>Miscellaneous Information and Comment</u>

a) Lenses and Aerial Cameras

It is stated that the creation of a wide-angle objective with sufficient light intensity and no appreciable distortion was considered by German and American experts to be quite impossible. Nevertheless, the Leningrad Institute of Aerial Photography started making the attempt and produced the first sample in 1934. (Liar-6). This had considerable optical drawbacks - though its resolving power was claimed to be satisfactory - it had distortion, chromatic and spherical abberations, astigmatism, and bad vignetting effects. (!) The Russar type of lens was first produced in 1936 but its resolving power was low. (9-12 lines a mm.) However, the new types of Russar lenses are considered satisfactory for small-scale aerial stereoscopic photography. Note that there is no claim that these lenses are satisfactory for large scale mapping. A comparison is made as shown in the following table with the Zeiss Topogon much to the latter's disadvantage.

Objective	f in mm.	Relative Aperture	Angle of View in °	Size of Photograph in cm.	Resolving Power in lines to 1 mm. at the edge of image	Distortion in 0.01 mm at the edge of image
Russar -1a	100	1:5.3	140	18 x 18	12	5-7
Russar-5	120	1:4.5	104	23 x 23	15	5-7
Russar-19	100	1:5.3	104	18 x 18	15 - 20	5-7
Russar-22	70	1:8	122	18 x 18	15 - 20	1-2
Tafar	200	1:4.5	70	18 x 18	40 - 60	Less than 1
Topogon	100	1:6.3	93	18 x 18	20 - 25	25 - 30

In this table the resolving power and distortion of the lenses are given only at the edges of the image. This does not constitute a fiar comparison. The earlier cameras built by the Russians were plagued with shutter trouble. Of historical interest is the statement that a 9-lens camera designed by Drobyshev was constructed in 1931.

(b) Aircraft for Aerial Photography and Navigation

A table is given in which are shown the basic characteristics of aircraft available for aerial photography in 1945. Of the six types mentioned, only one - the P-Z Sesquiplane - had a practical ceiling of over 16,000 feet. Considerable attention is given to navigation for aerial photography, and apparently course indicators of the sun compass type and statoscopes of the Mendeleyev type (Finnish?) were in use at the time of writing. The preparation of flight charts from the best available maps of the region being flown is stressed and it is strongly recommended that such maps be given additional emphasis in bright colors, for features such as forests and highways, to facilitate the general orientation for the pilot.

(c) Original Instrumentation and Techniques

It is evident that up to 1945 the Russians had not succeeded in producing many instruments which were not more or less copies of foreign instruments. A notable exception is the stereometer of Drobyshev previously mentioned.

Much attention is paid to photorectification and very little to the universal type of stereoscopic instrument. It is stated that the Zeiss multiplex is sometimes used for extending elevation control and that the Canadian grid method has its application in certain parts of Russia. The Brock method of mapping is briefly described and one surmises that it has influenced Russian thinking to a considerable extent.

The Stereo-Universal of Skiridov for obtaining relative orientation is claimed as an original instrument though it is admitted that it is similar in concept to Fourcade's stereogoniometer. The topographic stereoscope of Romanovskiy is very suggestive of the Barr and Stroud topographical stereoscope. The double projector of Drobyshev seems to be a descendent of Fourcade's double projector described in 1940 in the transactions of the Royal Society of South Africa. Graphics seem well advanced and the methods of radial line triangulation described probably have been influenced by the Finnish work on this subject.

APPENDIX III

General Discussion [redacted] 25X1A5a1

of

Geodeziya, Tom IX, 1949, Chapter 4

"Small Scale Aerial Photography" (10)*

by Konchin, M.D., Rusinov, M.M., Yutsevich, Yu.K. and Sokolova, N.A.

A. Summary and Conclusions

This is a medium-detailed handbook or encyclopedia on mapping methods and instruments. The theory appears to be well-developed, and current with ours in the main, except possibly in the error theory. Accumulation of error is mentioned and formulas are given, but they are simple, and I doubt that careful theoretical error studies have been made. The importance of error accumulation has only recently been realized here, however, so if the U.S.S.R. is behind in this respect it is by only a year or two. In the experimental investigation of errors and accuracy of primary measurements they seem to be a little ahead, probable errors for the various settings and material distortions being given. For example, it is stated that the error in parallax measurement caused by image motion has been found experimentally to be 1/20 of the computed amount of motion. No such figure has been measured in the U.S.A. I cannot tell, of course, how reliable their results are, but at least the importance of such quantities is recognized.

In general the mapping methods used are cruder than ours, using more graphics and computation and fewer advanced instruments. This appears to

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be due to two things: the materials are not as good as ours, and the general run of available instruments is of a lower order of accuracy and productivity. The latter may be due to shortage of good design engineering or production techniques; the reason is not known, but the statement is made once that a certain instrument was not in production due to "technical difficulties". Statements are made, of course, that the Russian instruments are simpler and therefore better, but this may be discounted. At any event, most of the instruments are simple -- for example, telescope optics are not used much in the stereoscope.

The result is, that the graphical methods and use of computation appear to be advanced further than ours. The methods they use for 1:50,000 and 1:100,000 maps are similar in structure to the methods we use (in trimetrogon work) for 1:500,000 and 1:1,000,000. The organization of the work is very reminiscent of our Brock method, and is good. From the descriptions given, however, the accuracy obtained in 1:50,000 mapping must be less than we have in such maps. And the amount of field control and office work is greater than we need. They seem to fly somewhat lower than we do.

The cameras used are wider angle than ours, and on the surface the lenses appear to be better. This is fictitious, however. The lenses are rated f/5.6 and f/6.3 but I doubt that they work at better than f/8 or f/11. This is implied by the shutter speeds used: 1/50 to 1/100. A small part of the slow shutter speeds may be caused by slow film (probably slower than ours, since the rated resolution is 60 l/mm) but most of it must be required for small lens stop. Hence the lenses are most likely f/8 or f/11 lenses, with a large enough opening so that they can be rated f/5.6, but will not work there. This is conjecture. Complete test data on resolution and distortion would be required for a reliable evaluation.

One instrument they have would be useful to us: a small rectifying projector using reduced diapositives, for use where we use the vertical sketchmaster. The idea is not new to us, but we have never gotten around to making one.

In summary, their mapping methods are ingenious and theoretically sound, cruder than ours, almost certainly less accurate and less efficient, with a shortage of good laboratory instrumentation, and a large use of simple mirror stereoscopes rigged up to do a little more than our simplest instruments. There is some disagreement between different parts of the chapter as to whether certain lenses are or are not in production.

B. Précis and Discussion

I. Small Scale Aerial Photography

a. Introduction.

Need for aerial mapping to replace ground methods: cheaper, especially in wild areas; possibility of reconnaissance mapping over large areas; use of less highly trained people. This reads very much like our discussions on the same subject.

b. Compilation of maps at 1:50,000 and 1:100,000 scale.

1. Aerial Photography. Wide fields desirable for precision and efficiency, but multi-lens cameras complicate processing and not precise enough. Hence, wide angle lenses used: Russar-1, Russar-22, Topogon. Latter discarded for having too much distortion. Russar-1: 100 mm F, 100° field. Russar-22: 70 mm F, 120° field.

Discusses effect of material and equipment distortions on parallax and height measurement. Of note:

Photo-papers shrink 0.3%, a little worse than ours.

Differential film shrinkage is 0.1%, compared with 0.03% for ours

Accidental local film distortion averages .04 mm, compared with about .01 mm for ours.

Glass diapositives, or photo-paper pasted on glass is used for more precise work (1:50,000).

Emulsion resolving power 60 l/mm, aerial film.

Resolution of Russar-1: 12-15 l/mm. Russar-22 not given.

Anti-vignetting filters are used.

States that all errors are proportional to size of photo or camera focal length; therefore using larger cameras would give no improvement. This is false.

Frame size 180x180 mm. Russar-19 and -1a used for 1:50,000 maps, Russar-22 for 1:100,000 maps. (But note statement later, that Russars above-16 have not been produced).

Photo scale 1:30,000 for 1:50,000 maps

Photo scale 1:50,000 for 1:100,000 maps. Note that this means altitude of 3500 meters.

Exterior orientation records kept:

Statoscope (±2 m. accuracy)

Horizon, through auxiliary camera chamber attached to camera. Sometimes two. Accuracy ± 7 to 10 min.

Level bubble -- auxiliary indications.

Watch -- gives air base to ±3% .

Sun photographs, for angular orientation. Ref. made to Santoni cameras, no Russian make mentioned.

But: above not all in routine use.

Experiments in progress on radio altimetry (interference) and gyroscope tilt determination.

2. Photogrammetric Control Methods.

"Straight-Line Method" for low relief.

Spatial Triangulation for high relief.

The straight line method is an ingenious method for bridging elevations, using two adjacent and overlapping strips. It computes elevation differences by the standard parallax formula, assuming the photographs are level, and requires an (uncontrolled) mosaic of the strips. Hence it has only limited accuracy, theoretically. Work is graphical and computation. Stated to be used where relief does not exceed 500 to 100 meters per model, and can bridge 4 to 5 models for 1:100,000 maps, no bridge at 1:50,000. It can also be used to interpolate elevations on a single model.

Spatial Phototriangulation. Used widely for 1:100,000 maps. For 1:50,000 maps only in mountainous areas because distortions cause too much error for flat country. In flat country, "Method of Continuation on Stereometer" is used. Steps in Spatial Triangulation are as follows:

(1) Measure y-parallaxes in stereometer.

(2) Compute relative orientation, and convert to pseudo-absolute with respect to an arbitrary plane.

(3) Measure x-parallaxes and compute elevations. Adjust to control.

(4) Meanwhile, triangulate planimetric positions using nadir point in mountains, or nadir or principal point in plains. Probably a radial line plot, though it doesn't say so. This gives air bases for step (3).

Also, the "Lateral Traverses Method" is widely used for 1:100,000 scale. This is apparently a mosaic of a single strip, holding to the center points for direction.

Also, the Multiplex is used for bridging. From the tenor here and in other places it seems that there are few multiplexes.

3. Planimetric and Topographic Mapping

(1) Planimetry. Shows that pictures are not maps, due to tilt, scale and relief displacement. For plaimetric maps of flat country one could rectify and ratio to horizontal control, but this is too complex and is not used. Similarly for planimetric maps in mountains one could rectify to an inclined plane, or even to several such planes in zones on one photo. In general, to correct for relief displacement one must vary the enlargement at each elevation. The portions could be assembled into a mosaic, but this gives too many pictures. Hence, it is easier to vary the ratio in a projector, and draw from the projected image.

This is not usually done on the rectifier, rather done with a projector and pantograph. (Is there a shortage of rectifiers?)

This sounds like the system of laying a radial line plot, projecting and tracing, but dressed up with theory.

Also they have an instrument similar to Vertical Sketchmaster, but the perspective relations of the photo not maintained. Statement that parallax is eliminated is not true. Instrument is more complicated than sketchmaster, probably easier on the operator, but no better in function. Enlargement of photo is not possible.

Small rectifying projector, using reduced diapositive, also used for sketching operation, in conjunction with pantograph. This we should have. Up to 4x reduction.

(2) Topography at 1:50,000. For topography, Topographic Stereometer is used. This is a stereometer like the Brock (but with simple optics -- mirrors only) but fitted with mechanical corrections to reticles and parallax displacement, to correct for tilts. Photos remain flat. Uses contacts

on paper posted to glass. (seems crude) For maps of flat areas at 1:50,000, 5 elevations necessary in each model. (Note: Fig. shows 7 points.) Orient to known elevations, then contour on the photos.

Large amount of field control lowers the efficiency of this. Hence, for 1:50,000 maps, extra operations are undertaken. They measure y-parallax and compute relative orientation; also, use "Straight Line Method" or others to compute elevations of center points. Hence, field control necessary only along sides of strip. But this means C-factor must be low. We found in Brock that this doesn't work -- and the Brock equipment is much more precise. Probably no more than 500 C, and probably more nearly 300 C.

Also describes scheme for using two strips jointly with control along side lap of every second strip. Properly adapted this might work in some of our methods.

Note: suggests mean error of parallax difference measurement .03 mm. I do not believe this possible with instrument described. Implication is made that the method works at 600 C, if bridging is not required.

The contours are drawn on the photos and corrected for tilt and relief along with the planimetry. This is similar to some parts of the Brock method.

(3) Relief Maps at 1:100,000. Relief is based on methods of Spatial Triangulation or Straight Line Method, giving a net of elevation control, at least 6 on each model, plus any "characteristic" relief points. Then contours are drawn on the prints, by interpolation between elevation control points -- really, form lines -- not by Stereometer.

Can later be transferred to a mosaic, or a manuscript. Describes stereoscopes:

Cyclops, half a stereoscope at a 30° slant

Chamber Stereoscope: fixed base with movable mirror stereoscope and adjustable for scale differences up to 20

Barr-Stroud topographic stereoscope less often used. Corrects tilts by tilting pictures on ball and socket joint, like our KEK and has reticles above picture plane, like KEK, but they use threads, and reticles are separated horizontally for parallax changes.

Stereoscopic Drawing Instrument. Stereoscope with half-silvered central mirrors, like Spurr's gadget. Photograph tables have tilt and swing. Use a "multiplex table" for drawing. Draws in orthogonal projection.

(4) Geodetic Work. Which means ground control, or field work. Low order triangulation used in mountains, and "geometric nets" (?) in plains and open areas. "Tacheometrical" survey in closed areas. Elevations are run by alidade traverses, and run up to 25 km. between control, or 15 km. from control to a pass point.

Also barometric leveling. Use one-base method, out to 10 to 20 km. for 1:50,000, more for 1:100,000.

In mountains, sometimes measure vertical angles from a control point; and pick horizontal distances from the radial line plot.

Sometimes the surveyor takes the photos and a stereoscope into the field, and draws the contour lines on the photos while running his levels. Also, sometimes the planimetry is done from aerial photos and the contours by plane-table.

c. Small Scale Cartography

By compilation if material exists. If not, reconnaissance photography, using multi-lens cameras: 4-lens TAFAM (USSR), or Fairchild T-3-A.

TAFAM: 1 vertical, 100 mm. F, 84° lateral field; 3 obliques, 70° tilt, 2 lateral and 1 backward, 170 mm F gives 56° lateral field. States 195° lateral field; hence almost no overlap in chambers. Photographs the horizon. Fly at 4 km., strips 30 km apart.

Using TAFAM, map compiled by graphic-computation methods described earlier, since rectification of 70° tilts too hard. If T-3-A is used, pictures are rectified.

Omitted pages 228-245 apparently describe camera perspective, light loss, vignetting, lens characteristics, calibrated focal length, lens aberrations, and several lenses.

(translation is sketchy from here on)

II. Wide Angle Objectives

Russar-1 apparently has small distortion (< .05 mm to 50°) but very large curvature of field at f/10, even though lens is rated f/5.7. Russar-16 is very wide angle (126°) and looks good except (a) very large field curvature and only f/12. As of this date (1949) the later lenses, Russar 19-26, have not reached production.

III. Aerial Cameras

<u>MAFA Aerial Camera</u>: Russar-1 or Russar-19, 98 mm F, f/6.3, 110° field, only 104° used. Shutter speeds 1/60 to 1/180 or 1/45 to 1/130, 0.9

efficient, frame size 180 mm sq., using 190 mm film in rolls 22.5 meters, giving 150 exposures. Intervalometer works 10 to 120 sec. Gross wt. 80 Kg. Camera uses both vacuum, pressure and edge clamping to flatten film.

Apparently camera has metering trouble. Also, image plane with fiducial marks is on magazine, not cone, and registration trouble arises.

Remark: "The construction of aerial cameras is quite simple." Later models moved the film plane to the cone.

Topo Camera Tafa-3: Two cones:

Russar-19, 98 mm F, f/6.3, 110° field only 104° used shutter speeds 1/25 - 1/75, 90% eff.

Tafar, 200 mm F, f/4.5, 63° field, shutter speeds 1/50 to 1/150, 80% eff.

Image frame 180 mm sq., plus 15 mm for statoscope, level, watch and data card. Roll size 190 mm x 50 m, gives 250 photos. Flattening by suction and edge clamping. Intervalometer 5 to 110 sec. Weight about 40 Kg.

Item: when film edge is clamped, needles pierce the edge of the film, so that you can tell where to cut the film in the darkroom, if not used up.

This was the first Soviet topo camera, and has proved satisfactory.

Topo Camera Tafa-2. Russar-19, 127 mm. F, f/6.3, 230 mm. sq. image, 240 mm x 50 m. film, 200 photos. Shutter speeds 1/25 to 1/100, 90% eff.

Descriptions of mapping instruments, fragmentary translation.

Statement: Multiplex is used in USSR only for establishing control in bridging.

IV. Photogrammetric Instruments

Stereograph of Drobyshev. Mechanical restitution. Photos stay horizontal. None manufactured as of 1949, due to technical difficulties.

APPENDIX IV

Discussion of Stereofotogrammetriya (Stereophotogrammetry) by A. S. Skiridov(?), 1951*

25X1A5a1 [redacted]

A. GENERAL STATEMENT

This book was not fully translated, which made evaluation difficult. However, the chapter and section headings were translated, the book is profuse with figures and formulas, and some knowledge of methods, instruments and terminology had already been gained from reading Geodeziya (Appendix III), Drobyshev (Appendix V) in translation. Hence, I feel that I was able to get a fairly good understanding of the book.

B. GENERAL REVIEW OF METHODS

The most important general methods of mapping used in USSR seem to be: plane-table, differentiated methods, and universal instrument methods. All of these appear to have major usage. The differentiated method seems to be used more than the universal, and to be the pride of the Russians. The multiplex does not seem to be used at all as a mapping method, but only for spatial triangulation.

The plane table we are not interested in. The universal method is about the same as we know it. The method of differentiated processes is similar to the Brock method. It is the same in basic concept, but has been extended and improved in some important respects, and in a few respects is not as good. Thus we have the following tabular comparison of

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the major methods of mapping by aerial photography:

Method	U.S.	Europe	USSR
Universal	some	major	considerable
Multiplex	major	some	negligible
Brock	negligible	none	major
low-order (contour-finder)	some	sone	some

It is ironical that the only American mapping method -- the Brock -- should have been neglected here, but taken over by the Russians, and that one of the better European inventions, the Multiplex, should have been neglected there but taken over by us.

The Photogrammetric Theory is well developed in the U.S.S.R. The theory is as well developed here, but the major difference seems to be that there is no application of the more advanced theory here, and the knowledge is not wide spread. In the U.S.S.R. the more advanced theory is contained in this textbook, even to calculation of higher-order effects and how to apply them in orientation of photos, and so apparently taught in the higher courses.

The major trends in Russian developments seem to be:

1. A recognition of the importance of the optics, and a development along those lines far exceeding our own, if the reports on their lenses are true.

2. The tendency to make the corrections for orientation mechanically, rather than by homolog or optical means.

3. The use of numerical computations where we tend to compute by analog, or not to compute explicitly at all.

A major criticism is a lack of recognition of the importance of redundance, or the use of redundance to simplify the computations rather than to reduce the errors. This tendency is noticeable in American work as well.

C. RUSSIAN MAPPING PROGRAM

Until about 1951 or 1952 the basic Russian map scale has been 1:100,000 with 20 m. contours in flat areas, 40 m. contours in mountainous regions. In the sparsely settled, outlying areas the publication scale is 1:100,000 and contours are 40 m., but the planimetric accuracy requirements are reduced to be equivalent to 1:200,000 scale. Apparently, from remarks made later in the book and from remarks in Geodeziya, there must have been auxiliary mapping at 1:50,000, and some large scale mapping.

Starting as of now the future plan is to map the country at 1:25,000, with selected areas filled in at scales between 1:10,000 and 1:2,000.

D. REMARKS ON INSTRUMENTS

Instruments remain pretty much as discussed elsewhere (Geodeziya and Drobyshev) with one exception. The 70 mm. Russar 22 aerial camera lens appears to have come into use by this time. The ultra-wide angle multiplex to use the 70 mm. pictures in triangulation appears to be available and used. The Stereometers do not appear to have been adapted for 70 mm. yet: they are constructed for 100 mm. photos, with a minimum setting of 90 mm. Skiridov gives correction formulas for using the existing stereometers with 70 mm. photos. Also, the photo scales for the smaller scale maps have been increased. Geodeziya gives photo scale of 1:50,000 for maps at 1:100,000, and 1:30,000 for maps at 1:50,000. Skiridov gives ranges 1:55,000 - 1:75,000 and 1:30,000 - 1:40,000 respectively. In each case the upper end of Skiridov's ranges would correspond to flying at the same height but using a 70 mm. lens instead of 100 mm.

Also, Skiridov describes as a separate type of instrument, which we will call Generalized Instruments, certain particularly Russian instruments. These employ the Russian mechanical corrections for orientation, but perform the functions of the Universal type instruments. They seem to be either the better stereometers with pantograph arrangements for changing projection, or a cross between a stereoscope and the multiplex.

E. PROCEDURES DESCRIBED BY SKIRIDOV

A. For Horizontal Control

1. Ground triangulation
2. Ground traverse
3. Spatial triangulation, by
    a. Universal Instruments
    b. Stereometer
    c. Multiplex
    d. TsNIIGAik (differentiated process)
    e. Undistorted Model
    f. Stereo-phototheodolite (Brief)
    g. Mechanical triangulator (Brief)
4. Astronomical Stations
5. Radio Distance Methods.

Note: no mention is made here of our radial-line method, and apparently it is not used. Geodeziya mentions also, and lays stress on, spatial triangulation by measurement of coordinates on stereocomparator and numerical computation. This is probably the method of TsNIIGAiK. Except for Extension on Stereometer, all horizontal control methods used determine elevations as well. Extension on Stereometer requires a line of levels down every second side-overlap, but then it can determine elevations at the other points.

B. For Vertical Control

1. Ground leveling
2. Barometric leveling
3. Straight-line method (most important)
4. Methods of Spatial Triangulation. See note above.

Note: Sometimes the straight line method is used to get the line of levels required for Extension on Stereometer, and this then becomes a complete bridging method. This is not accurate enough for large-scale work.

C. For Auxiliary Control

1. Statoscope
2. Horizon Camera
3. Radio Altimeter

   etc.

Note: Extent of use unknown.

D. Other methods -- for contouring, planimetry, orientation, etc., are much like ours in the corresponding processes. There are some differences, but there is no point in going into this in detail. (See Geodeziya for the Differentiated Processes Method.) Also, non-linear interpolation is used when contours are interpolated from a few elevations.

F. GENERAL NOTES

The Method of Differentiated Processes uses a 600 C-factor. Whether this is equivalent to our type of C-factor or not is unknown, since the accuracy of the contours (50% or 90%) is not stated. The Photo Scales used are:

Map Scale	Photo Scale
1:5,000	1:7,500 - 1:10,000
10,000	15,000 - 17,500
25,000	17,000 - 20,000
50,000	30,000 - 40,000
100,000	55,000 - 75,000

The straight line method is said to determine elevations to an accuracy of H/700 to H/1100. This depends on measuring long lines to an accuracy of .03 mm. to .05 mm. I doubt that the instruments and materials described can give that much accuracy.

Much mention is made of bridging, and it apparently is used extensively, but no experimental determinations of accuracy are given.

Accuracy of contouring by three methods was determined by a field test in 1945. Height error was related to average slope of terrain, with the following results:

Let <u>a</u> be average terrain slope, m be standard error in meters. Then:

Plane Table:	m = 0.8	15.0 tan a
Stereometer:	m = 1.3	4.4 tan a
Stereoplanigraph:	m = 0.8	1.2 tan a

Test was made on a 1:25,000 scale, 5 m. contour map.

The Russar-25 lens used in the ultra-wide angle multiplex is said to have F = 20 mm., f/10, 122° field, resolution of 100 l/mm. at center, 60 l/mm. at edge. Every effort should be made to secure either an actual lens or the drawings for the Russar-22, 70 mm. lens and the Russar -25, 20 mm. lens.

APPENDIX V

ANALYSIS OF SOVIET PHOTOGRAMMETRIC INSTRUMENTS

Based on Information Contained in a Book by

F. V. Drobyshev,

"Fotogrammetricheskiye Pribory i Instrumentovedeniye"(11)*

(Photogrammetric Apparatus and Instrumentation)

1951

[redacted] 25X1A5a1

I. General Analysis

A review of Soviet photogrammetric instruments, based upon descriptions in the textbook, "Photogrammetric Instruments and Instrumentology" by F. V. Drobyshev, Moscow, 1951, is generally disappointing from a technical point of view. No new principles are disclosed, and the solutions which have been selected for development into working models seem to be more complicated and less direct than those employed in western Europe and the United States.

The mechanical and optical precision expected in Soviet instrument design is apparently somewhat lower than in western Europe. The textbook specifies that photographic image positions must be determined within ± 0.02 to 0.05 mm. Both Wild (Swiss) and Zeiss (German) require 0.01 mm in their precise instruments; Multiplex and Kelsh plotters used in the United States give approximately 0.10 and 0.07 mm. respectively. Furthermore, no mention is made of corrections for residual lens distortions; western Europe manufacturers have given much thought to this problem, and

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Approved For Release 1999/09/01 : CIA-RDP79-00202A000100070001-9

some method of correction is incorporated in each of the precise instruments. Another indication of precision is found in the size of the measuring marks. The Russian instrument designs call for marks of 0.05 to 0.20 mm. in diameter; Wild specifies 0.04 mm (A5) and 0.02 mm. (A7 and A8). One instance in which the Russians seem to have been ahead of developments in western Europe is the use of luminous measuring marks of various colors. These were not introduced by Zeiss until the Model C-7 Stereoplanigraph about 1948. They have still not been accepted by Wild and Santoni (Italian). The Russians use them even in the simpler instruments.

The lower precision and the different emphasis in instrument design may probably be attributed to the fact that the Soviet problem has been largely the mapping of extensive areas at scales of 1:50,000 and 1:100,000 and smaller. In western Europe the trend has been towards much larger scale mapping with a consequent increase in precision requirements.

No credit is given anywhere in the book to any manufacturer of photogrammetric instruments outside of the U.S.S.R. A number of the instruments described are exactly the same as Zeiss designs. It is most probable that the descriptions are of the Zeiss instruments themselves. If not, the instruments are direct copies of the Zeiss products.

This applies specifically to the following devices:

Small photo rectifier FTM
Large photo rectifier FTB
Horizontal stereocomparator
Radial triangulator
Stereoplanigraph C-4

None of the other western European designs has been adopted. Undoubtedly the reason for this is that the Zeiss factory in Jena, Germany, is now under Soviet control. The realization of space rays by mechanical rods, successfully employed by Wild and Santoni, has not been used, although it is mentioned briefly as a possible solution.

A more detailed analysis of the different types of instruments follows.

II. Instruments

1. Photo Rectifiers

Five different instruments are described. The first two of these are merely enlarging and reducing projectors having no provision for tilting. Automatic focus is obtained in the first instrument by means of a rhombic inverter and in the second by a cam and follower. Both are extremely large instruments with limited applications.

The third instrument is a true rectifier but has a very limited range. The adjustment of focal distances is obtained by a spiral cam controlled by a foot disc. This solution undoubtedly does the job, but takes up a great deal of room.

The fourth and fifth instruments described are direct copies of the Zeiss small rectifier, SEG IV, and large rectifier, SEG I.

Nothing comparable to the Bausch and Lomb fully automatic rectifier is described.

2. Stereocomparators

Two stereocomparators are described. The first is exactly the same as the Pulfrich-Zeiss stereocomparator, no longer manufactured.

In the second instrument the plane of the photographs has been tilted to make observations more convenient for a seated operator. Also the least reading has been reduced from 0.02 to 0.01 mm.

Stereocomparators were originally developed for work with terrestrial photographs. They have never been in favor in this country and have been largely replaced by semi-automatic plotting instruments in west European countries.

They are used primarily for obtaining coordinate measurements for analytical methods, for analytical radial triangulation, and for non-cartographic applications such as astronomical measurements.

At present, Nistri in Italy and the Cambridge Instrument Company in England manufacture stereocomparators. The precision of measurement in each of these instruments, 0.01 mm, is the same as that claimed for the Russian device, although the system used for obtaining these values is different in each of the three. In the Russian instrument full length glass scales read by means of a mechanical micrometer are used. Nistri uses a precise grid superimposed on the photograph in the plate holders; coordinates in each grid square are read by means of a spiral micrometer. The British instrument uses a calibrated grid imposed on the photographs in the camera when the exposure is made; coordinates in each grid square are read by a micrometer drum. This automatically compensates for film shrinkage, etc. Both the Italian and the British instruments have full circle rotation of the plate holders making them adaptable for radial triangulation. This feature is apparently not provided on the Russian instrument.

It is stated that the collimation system of observation was applied by Drobyshev seven years before it was adopted in foreign countries. This is doubtful since Pulfrich used the principle in the first Zeiss Stereo-comparator built in 1901.

3. Stereopantometer Drobyshev

This instrument performs the same function as the Abrams Contour Finder, the Fairchild Stereocomparagraph, the Zeiss Stereotop, the Nistri Stereographometer, or any combination of mirror stereoscope and parallax bar. The Russian and Zeiss instruments move the photographs with respect to stationary measuring marks and stereoscope; the others move the stereoscope and marks with respect to stationary photographs. So far as results are concerned, one system is as good as the other. The first results in a more compact but more complicated instrument; the second is simpler and cheaper to construct. The Russian device introduces a luminous floating mark, probably a needless refinement in such an instrument. Nistri has an attachment for producing an orthographic projection at constant scale. The latest model of the Zeiss has a device for approximately correcting the effects of small tilts.

4. Stereometer Type Instruments

The three stereometer instruments described illustrate the results of a purely nationalistic development. No comparable instruments are produced in this country or in western Europe. All three designs are an extension of the principle of the stereocomparator based upon two premises:

1. Both photographs will be maintained in the same plane regardless of tilts which may have existed at the time of exposure.

2. The line of sight of the optical viewing system will be kept perpendicular to the plane of the photographs.

When tilted photographs are observed under these conditions, the observed values of horizontal (x or height) parallaxes and vertical (y or orientation) parallaxes will be in error. In order to correct these observed values the photographs must be moved in the x direction, in the y direction, and about a vertical axis not necessarily coinciding with the camera axis. These corrections are applied by ingenious mechanical devices which automatically introduce the required motions. In order to keep these devices simple, certain assumptions are made -- primarily that the tilts do not exceed three degrees. The settings of the correction devices are functions of the normal orientation elements.

A complete solution by this system would require three correction devices on each photograph. Apparently such an instrument has not yet been constructed. The three instruments described give only a partial solution, and further operations with the photographs are required in order to obtain complete map information from them. The instruments undoubtedly perform the function for which they were designed, but in view of the limited information obtained from them, they seem to offer no advantages over the instruments in use in the west. They are not adaptable for extension of control by bridging methods, and based on the simplicity principle, it is soubtful that a high degree of accuracy could be attained.

a. Topographic Stereometer of Drobyshev

The end product of this instrument is elevations of ground points and or contour lines drawn by hand directly upon unrectified photographs. In this respect it is roughly comparable to the Zeiss Stereotop or the Brock Stereometer, except that rectified photographs are used in the Brock instrument. All of these devices are subject to the limitation that each contour line is at a different scale.

b. Stereometer of Drobyshev

This instrument is a larger and more precise model of the Topographic stereometer. It is adapted to use either glass plates illuminated from below or paper plates illuminated from above. The y parallaxes are measured and the least readings of the correction devices are smaller so that more precise values of the orientation elements are obtained. Contour lines are drawn by a pencil attached directly to the instrument rather than by hand.

c. Kern Stereometer (Skiridov)

This instrument is designed solely to détermine the elements of relative orientation of a stereopair by elimination of the y parallaxes at five points. Elevations of contour lines are not determined.

d. Instruments of Direct Optical Intersection

These are projection type instruments operating essentially on the same principle as the Multiplex and Kelsh plotters. Again no new principles are disclosed, but several interesting innovations are described. It is stated that stereoscopic vision is obtained by the use of polarized projectors and spectacles. Western experiments with this system have not been successful.

5. Projectors

a. Double Projector of TsNIIGAiK (Drobyshev)

This instrument was apparently designed primarily for research in various means of viewing the stereoscopic model. It offers a correct solution but has drawback for practical application. Variation between camera and projector focal lengths and plate sizes results in different scales for horizontal and vertical measurements. Absolute orientation is obtained by tilting the base table which could make drawing inconvenient. The two projector instruments cannot be used for bridging.

b. Double Projector DPD-2 of Drobyshev

The instrument is designed for producing large scale topographic maps from contact diapositives. The projectors are disposed in a horizontal position and the relative orientation is performed by introducing rotations to mirrors placed in front of the objectives. A similar scheme was used in a German instrument designed by Gasser in 1915. Absolute orientation is still obtained by tilting the drawing table with respect to the fixed projectors.

The model may be viewed either by the anaglyph principle or by means of the blinking method. At present only Nistri applies the blinking method in a production instrument. Experiments have been conducted in this country but there is no unanimous preference for one method over the other.

In end product the instrument is comparable to the Kelsh plotter, but in construction and operation it is much more complicated.

6. Soviet Multiplex

In photogrammetric principles and operation this instrument is exactly the same as the instruments produced by Bausch and Lomb, Williamson, and others.

Optically, the ultra-wide angle coverage, 122°, and the use of aspherical condenser lenses are of great interest. A distortion free objective of this angular coverage and the specified resolving power of

60 lines per millimeter does not exist in western instruments. To be significant this lens must be complemented with a camera objective of equal angular coverage. It has not been found practical to mass produce aspherical lenses of high quality.

7. Instruments of Optical-Mechanical Intersection

There are many different solutions possible in this category. Those selected by the Soviets for development into working models are the same as those used in Western instruments. In pursuit of the national trend towards keeping the photographs co-planar, a system is described in which existing photo tilts are introduced by providing an adjustable joint in the space rods. A similar system was described in Swiss patents 251686 and 262481 by H. Wild in 1948, but no instrument using this scheme has been built.

a. Stereo Universal of Skiridov

This instrument, like the Kern Stereometer of the same designer, serves solely to determine the elements of relative orientation of two photographs by elimination of y parallax in five points. In this instrument the photographs are tilted, while in the stereometer instrument the parallaxes are corrected with the photographs maintained co-planar. The use made of this limited information is not described. It is probable that it is used for the settings of other instruments in which the photographs are actually plotted. Another possible use is to aid in determining the positions of nadir points and isocenters, after which the photographs may be used in radial triangulation with results equal to those obtained in space triangulation.

b. Radial Triangulator

The illustration, diagram of optical system, and description are precisely applicable to the Zeiss radial triangulator.

c. Stereoplanigraph S P B and C-4 (Konshin)

The C-4 seems to be a description of the Zeiss Stereoplanigraph C-4, while the S P B is the Soviet copy of the same instrument. The photograph of the instrument, the diagrams of the mechanical and optical systems show only minor discrepancies from the Zeiss. However, the Soviet model does employ luminous measuring marks, not incorporated by Zeiss until the model C7.

d. Stereoscopic Universal Instrument RP-6 (Konshin)

This instrument is an attempt to reduce the complexity of the stereoplanigraph to speed up map compilation. It is not a universal instrument at the term is understood here, since it is adaptable for use only with near vertical aerial photographs.

In principle the instrument is a combination of a K E K Plotter and a vertical sketchmaster. The photographs are oriented in space by means of angular and directional motions. The elements of relative orientation obtained in the Stereo Universal and Kern Stereometer of Skiridov are probably used for this purpose. The mirror stereoscope allows viewing of the entire model at once. Half silvered mirrors give the impression of the model projected upon the drawing table. Planimetry and contours are drawn by hand on this projected model. The instrument could not be expected to give a high order of accuracy.

APPENDIX VI

COMPARISON OF ACCURACY OF MAPPING PROCESSES IN THE U.S.S.R. AND USA

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Despite the criticism given to the C-factor, it is a useful measure of comparative mapping process efficiency provided, in making comparisons, that

(a) equivalent measures of contour accuracy are used,

(b) the vertical accuracy requirement is controlling, and

(c) physical conditions of use (referring to terrain and atmosphere) are similar.

As a practical measure, if these conditions are observed, the C-factor shows approximately how much map is obtained for a given effort, including not only the physical differences between mapping processes but also the effects of varying and not measurable factors such as personnel efficiency, haze, materials control, etc. As a technical measure, applied to some theoretically perfect or standard conditions, the C-factor measures the potential vertical information content of the photograph when the information is to be used by the process under consideration. In addition, when applied as a technical measure the C-factor is strictly equivalent to other incomplete technical measures such as precision of parallax measurement, contouring "spread", etc. Superior overall measures can be obtained only by more intensive process analysis than has yet been reduced to practice.

We will use the C-factor as a basis of comparison of Soviet and American mapping processes, on the basis of the limited information available.

Considering the conditions for comparability stated above in reverse order,

(c) we can assume that the conditions of use are similar, since the figures to be compared refer to average practice over the years and over the wholes of the two countries, and there are no outstanding physiographic dissimilarities between them,

(b) we will compare for large scale maps, where the vertical accuracy is controlling,

(a) we must examine the Soviet map specifications relating to contours and attempt to determine what an equivalent contour interval would be according to American specifications.

Skiridov states (p. 300) that for terrain slopes of less than 2°, the maximum error shall be 1/3 contour interval; for terrain slopes of 2° to 6° the maximum error shall be 2/3 contour interval; for 1:25,000 maps. The question is, what does "maximum error" mean? This is usually, in America, taken to mean the "95%" error -- not more than 5% of the points are to exceed the limit.

The American standard for contour accuracy is that 90% of the points are to be within 1/2 contour interval. The ratio of "95%" error to "90%" error is 1.2. Applying the factors to land of less than 2° slope (which we will use for our comparison), for the same accuracy the contour interval on the Soviet standard is

$$1.2 \times 1/2 \div 1/3 = 1.8$$

times the comparable American standard contour interval.

Skiridov states (p. 294) that the maximum theoretical C-factor (U.S.S.R.) is 600 for large scale maps and 1:25,000 maps in flat areas, and that actual C-factors are lower. Analysis of the photo scales used (p. 294 and later) and focal lengths as given later in the same chapter indicates actual C-factors of 300 to 400 (U.S.S.R.), in flat country at 1:10,000 and 1:25,000 maps. Converting these to American C-factors by use of the factor 1.8, we have for the U.S.S.R.:

Theoretical maximum C-factor:	1080
practical average C-factor:	540 to 720

These refer to mapping by stereoplanigraph and by the Method of Differentiated Processes.

Comparable methods in America have the following C-factors

	Stereoplanigraph and Brock	Multiplex	Kelch
Theoretical Maximum	2000	1200	1400
Average practice	1250 - 1500	600 - 800	1000

Thus, it appears that the average Soviet methods, as used, are about comparable to Multiplex work, and considerably less accurate than the best American methods. It is believed that the chief cause of the lower accuracy in Russian work, if it exists, lies in the photographic materials, since

(a) the permissible error in contouring is only 1.3 times the precision of primary parallax measurement on the photograph, according to Skiridov, and

(b) tolerances on distortion of photographic materials, as stated in "Geodeziya', is considerably greater than American tolerances.

It is probable that the planimetric accuracy is comparable to American practice.

APPENDIX VII

THE STRAIGHT LINE METHOD OF THE SOVIETS

The following translation has been selected for inclusion in this technical paper for three reasons; namely, because (1) the method described is one of the more original Soviet methods and (2) the method is an illustration of the relationship of Soviet photogrammetric methods to the specific and peculiar needs of that nation and (3) the method might be of some interest to those individuals interested in photogrammetric reconnaissance in this country.

The original paper may be found in the reference book, Geodeziya, 25X1A5a1 Tom II, Chapter 4, pp. 210 - 214 dated 1949. 25X1A5a1 [redacted]

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The "straight line" method of Romanovskiy, U.S.S.R., is based on the theorem that for any straight line lying in the object space photographed there corresponds a straight line on the photograph. And inversely, that for a straight line on the photograph there can correspond any line on the land, provided a plane can contain this line and the perspective center. In this case, such a line would not be imaged as a straight line on the adjacent photograph, except when all its points lie in the same basal plane, or when it is actually a straight line.

Let us suppose, that three points have been selected on the left photograph, lying on one straight line: a_1, b_1 and c_1; to these points correspond three points on the land: A, B and C (Fig. 157).

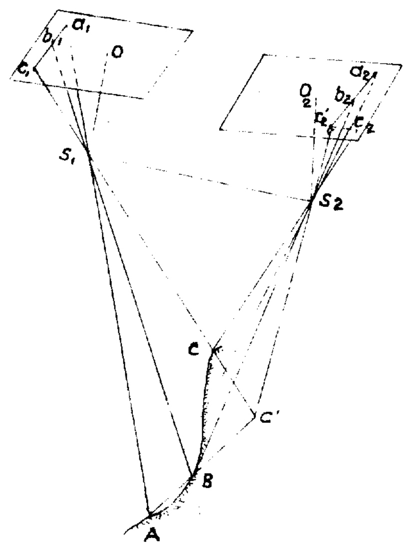

Fig. 157

If all three points A, B and C do not lie in the plane containing both perspective centers, (do not lie in the same basal plane) or are not located on the same spatial straight line, it is impossible to define a plane through these three points and through the second (right) perspective center of projection. Therefore images of these three points a_2, b_2 and c_2 would not be located on one straight line.

When we draw a straight line through points a_2 and b_2, the deviation of the point c_2 from this line is because of the elevation of the point C on the land above the line connecting A and B. To prove this we draw a straight line through points A and B, and produce it until it intersects at c' with the perspective ray s_1c_1. As ground points A, B and C' are located on one spatial straight line, their images a_2, b_2 and c_2' on the right photograph would also be located on one straight line.

The elevation of the point C' above point A can be easily determined from the right triangle (Fig. 158), when the elevation of the point B above the point A and the distances AB and AC' are known. Then

$$h_{C'-A} = h_{B-A}\frac{D_2}{D_1} \quad , \qquad (11)$$

where D_1 is the distance AB, and D_2 is the distance AC'.

As the point C does not lie on the spatial straight line AB, the point c_2 does not coincide with the point c_2'. In other words the deviation of the point c' from the straight line $a_2b_2c_2'$ occurs as a consequence of the elevation of the point C above the point C' and is expressed by the formula:

$$h_{C-C'} = \frac{H_{C'}}{b}\Delta pc \quad , \qquad (12)$$

where $H_{C'}$ is the altitude of the air base above the point C', b is the photo base above the point C on the scale of the survey, and Δpc is the difference in x parallax.

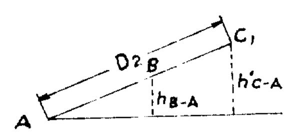

Fig. 158

Therefore the elevation of the point C above the point A is determined by the formula:

$$h_{C-A} = h_{B-A}\frac{D_2}{D_1} + \frac{H_{c'}}{b}\Delta pc \ , \qquad (13)$$

Determination of the elevation of the point C by formula (13) is inconvenient, as several values remain unknown (eg. D_1, D_2). Therefore this formula is transformed into a different one namely:

$$A_C = A_A + \frac{Qh_{B-A}}{1 + (Q - 1)\frac{h_{B-A}}{H_A}} + \frac{H_c' \cdot H_c}{Bf_k \sin\psi}\Delta p \ , \qquad (14)$$

In this formula A_C is the elevation of the point C; A_A is the elevation of the point A; H_A is the elevation of the camera station above the plane, containing A, H_c and H_c' - are the heights of the flight line above the planes, containing points C and C' respectively; B is the air base - ψ is the angle between the straight line and the image of the air base, Δp is the length of the perpendicular from the point c_2 onto the straight line $a_2b_2c_2'$.

Expression Q is determined by the ratio:

$$Q = \frac{d_2}{d_1} \ , \qquad (15)$$

where d_2 is the distance a_1c_1 and d_1 is the distance a_1b_1.

Formula (14) can be given in a more convenient form for calculation:

$$A_C = A_A + Qh_{B-A} + \frac{H_? \Delta p}{b.\sin\psi + \Delta p} - \Delta h_H - \Delta h_Q \ , \qquad (16)$$

where Δh_H and Δh_Q are the corrective terms computed according to the following formulas:

$$\Delta h_H = \frac{(2Qh_{B-A} + h_{C-A})h_{C'-C}}{H_A},$$

$$\Delta h_Q = (Q - 1)\frac{h^2_{B-A}Q}{H_A}. \tag{17}$$

The method of successive approximations is used, computing first the basic expression (14) or (16), and then the corrections and repeating when there is significant relief.

Therefore the straight line method makes it possible, given the elevations of two points on the left photograph, to calculate the elevation of the third point, located on the straight line through the first two. This solution can be extended through succeeding air-photographs and this permits a significant reduction in the number of vertical control points.

When this method is used the procedure is as follows: Two adjacent strips are taken, and carefully assembled. On one of the strips, in the zone of the side overlap, a straight line is drawn between two points whose elevations are known. The straight line between these points is produced and points are marked in the area of the triple overlap, on this straight line; these points must be marked and are then identified on the contact print of the adjacent strip. It is necessary that these points be imaged in the triple overlap of the adjacent strip; otherwise, other points must be selected. The first air-photographs of both strips are put in a stereocomparator or in a topographic stereoscope and are oriented in such way that the straight line, passing through three points of one photograph and two points of the other photograph, will coincide with the Y axis of the apparatus.

Successive fusion of the floating marks of the stereophotogrammetrical apparatus with identical points of both photographs enables the difference of the parallax of the third point in respect to the first two, which are fused with the Y axis of the instrument, to be measured. The first point (Fig. 159) has a known elevation, and the elevation of the second one is deduced according to the relief of the terrain.

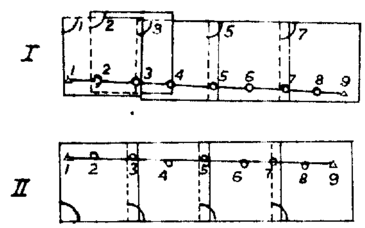

Fig. 159

The ratio Q is computed from formula (15), from the mean measurements of the distances d_1 and d_2 from the first point to the second and third points on both photographs. The values b and H are determined from the horizontal radial line plot by the ratios:

$$H_A = \frac{\ell f_k}{\ell_1} - \Delta h_A , \qquad (18)$$

$$b = \frac{b_1 k f_k}{H_A} , \qquad (19)$$

where ℓ is the distance between any two points of the same elevation, on different sides of the principal point and approximately at equal distances from it; k is the denominator of the scale of the radial line plot; ℓ_1 is the distance between the same points on the airphotograph (Fig. 160);

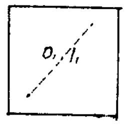

Fig. 160

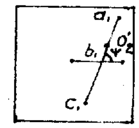

Fig. 161

Δh_A is the elevation of the first point above the plane containing the distance ℓ_1; b_1 is the distance between the principal points of the photographs on the radial line plot. Better results are obtained if b_1 is measured between the nadir points, but to do this it is necessary first to determine the elements of relative orientation. When the differences of elevation of the points on the straight line is small, it is sufficient to use the distance between the principal points.

The angle ψ (Fig. 161) from equation (16) can be measured with a protractor.

It is difficult to get the photographs in such a way in the stereoscope that the first two points appear to be exactly along the Y axis of the instrument; and this is not usually accomplished. Instead, after making measurements of differences of x parallax between the second and third points and the first one, a computation is made to bring the difference of parallax of the second point to zero using the expression

$$\Delta p_3 = \Delta' p_3 - Q\Delta' p_2 \, , \qquad (20)$$

Where $\Delta' p_3$ and $\Delta' p_2$ are the measured differences of parallax of the second and third points, and Δp_3 is the value for point 3 which would have been measured if the first two points had exactly coincided with the Y axis of the instrument.

When the elevation of the third point is determined, the second airphotographs of both strips are set up in the instrument in a similar way. On these photographs two points are plotted, whose elevations are known, and a fourth point, whose elevation is unknown. Similar measurements are made as before and with the aid of formula (16) the elevation of the fourth point is determined. These operations are repeated for all other airphotographs of both strips, including the last ones, on which the last point of the straight line has a known elevation. The difference between the known elevation of the last point and that determined by the straight line method, makes it possible to determine the error, which was made by the somewhat arbitrary determination of the elevation of the second point. A correction is then made to all the elevations determined of points located along the straight line by the expression

$$\delta h_i = \frac{\delta h_n L_i}{L_n}, \tag{21}$$

where δh_i - is the correction in elevation of a certain point i;

δh_n - is the difference between the known and determined elevations of the last point on the straight line;

L_i and L_n - are the distances from the initial point of the straight line to the point i and to the last point.

Certainly such a method of adjustment is only approximate and does not take in consideration systematic errors (eg. those produced by the distortion of the surveying lenses) in the measurement of differences of X parallaxes. Therefore, a diagram is usually constructed based on an analysis of the method when a sufficient number of known elevations are used and the character of the accumulation of errors is determined. On the strength of this diagram, corrections may be introduced in later operations.

The straight line method is applied in regions with small difference of elevations (on the average no more than 50 - 100 m. on a stereopair). When there are greater differences of elevation points are selected which appear to lie approximately at the same elevation. For the scale of 1:100,000, distances between terminal points equal to 4 - 5 bases are permitted. For the scale of 1:50,000, determination of elevations by the straight line method is usually limited to one stereopair, and then not in the side overlap. The accuracy of elevations by the straight line method is determined by the formula:

$$\sigma = \frac{\delta}{4}\sqrt{\frac{n^3 + 3n^2 + 3n}{3}}, \qquad (22)$$

where δ is the error of one transmission and n is the number of transmissions. The error of one transmission usually depends on the accuracy of the determination of the difference in χ parallax, and therefore:

$$\delta = \frac{H}{b}\,\delta_p, \qquad (23)$$

where δ_p at the present time can be accepted as equal to $\pm$ 0.05 mm.

The sine rulers of Drobyshev are often used for determining elevations by the straight line method. These give a sufficiently accuract result and are very simple.

These rulers (Fig. 162) consist of two glass plates, each having an opaque line down their centers. One plate is rectangular, and the other has one edge cut at an angle of 6°. To determine the difference of χ

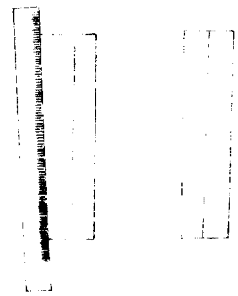

Fig. 162

parallax by the straight line method, the airphotographs are adjusted under a stereoscope and the rectangular glass plate is located on one of the photographs in such a way, that all three points lie under the opaque line. The line of the second plate is laid over the two initial points of the second airphotograph. One sees therefore one spatial line, combined with the two initial points. As the third point does not coincide with this line at this stage (does not lie on the same spatial straight line), it is necessary to shift the sine ruler in a direction perpendicular to the line. For this purpose a metallic scale with millimeter divisions is layed along the sloped edge of the sine ruler. The scale reading on the scale opposite the edge of sine ruler is recorded. Now the sine ruler is moved along the metallic scale until the third point coincides with the spatial line. The number of millimeters on the metallic scale, passed during this shifting are counted. This number, divided by 10 and multiplied by sin 6^{o} gives the value of the difference in x parallax.

In many cases these rulers can also be used for the measurement of the difference of x parallax of points not located on one straight line. For this purpose two sine rulers and two metallic scales are used.

In this procedure the airphotographs are oriented along the principal point base line, and the lines of the sine rulers are fused with identical images on the airphotographs, at positions perpendicular to the principal point base line. The metallic scales are then placed along the sloped lines of sine ruler. One of the rulers is monocularly shifted so as to coincide with a second point. This shifting is measured on the metallic scale. After this, the second sine ruler is stereoscopically fused with the image of the second point on the second photograph.

The difference of both shiftings, divided by 10, and multiplied by Sin 6^o is equal to the difference of x parallax between the first point and the second one.

APPENDIX VIII

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